ESD-TDR-63-182 W-5752

# UNINTERRUPTED POWER SUPPLY SYSTEMS FOR THE NUDETS (477L) PROGRAM

TECHNICAL DOCUMENTARY REPORT NO. ESD-TDR-63-182

May 1963

A. M. Ranford

Prepared for

477L SYSTEM PROGRAM OFFICE

ELECTRONIC SYSTEMS DIVISION

AIR FORCE SYSTEMS COMMAND

UNITED STATES AIR FORCE

L. G. Hanscom Field, Bedford, Massachusetts

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Contract AF19(628)-2390 Project 477

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ABSTRACT

A highly reliable, uninterrupted electrical power supply system is a vital requirement for the NUDETS (477L) project. In this study, various techniques for providing this high quality electrical power are analyzed, and recommendations are made for selecting the most suitable systems for this program.

# UNINTERRUPTED POWER SUPPLY SYSTEMS FOR THE NUDETS (477L) PROGRAM

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FIGURE PAGE

# CHAPTER I

## FOREWORD

In response to a written request by Department D-17, an engineering investigation has been carried out into the means of providing the various subsystems of the 477L NUDETS program with highly reliable, uninterruptible power supply systems. The results of this investigation are presented in this report.

In order to define more accurately the requirements which the power supply systems must meet, the following design criteria was furnished and/or established to serve as the basis for the study:

1. Two power levels were specified:

Type I - 3 KW net power load - to be supplied at 115 Volts, A.C., single phase, 60 cycles per second.

Type II - 50 KW net power load - to be supplied at 110/208 Volts, A.C., three phase, 60 cycles per second.

2. To provide a practically transient-free, high quality, uninterruptible power supply, the system will be designed so that the critical load will be isolated from the incoming normal power supply at all times.

3. Outside commercial power will be used as the normal input to the uninterrupted power supply system.

4. Certain Type I' installations will be unattended, but they will be visited periodically by maintenance teams who will service the electronic equipment.

5. The attended Type I and all Type II installations will have full time power plant operators available to monitor the power generating equipment and perform the necessary maintenance.

6. An isolation period of 36 hours has been chosen as the design point for emergency operation of the power supply in the event of failure of the normal commercial supply. However, the curves have been extended from that point downwards to a period of one hour and upwards to a period of 168 hours (1 week) to permit cost of operation comparisons to be made for other time periods of emergency operation.

7. It is anticipated that during the initial phase of the program the electronic system components at the sites will be simplexed.

8. At the present time, approved equipment specifications have not been received. Therefore, the power supply will be designed to meet the over-all systems requirements as stated above. At such times that the specifications become available, the design will be again analyzed and adjustments made accordingly.

9. Since the NUDETS program will be implemented in the near future, the study will be limited to power generating systems which are available today and which have proven themselves to be highly reliable.

10. It is assumed that an adequate facility, properly ventilated and heated, will be provided at the various sites to permit installation of the power generating systems without further modifications.

# CHAPTER 2

## INTRODUCTION

A continuous power source is one which provides an uninterrupted source of power for a given period of time regardless of the condition of the normal power source. The continuous power source utilizes stored energy of various kinds for the period of time the normal source is unavailable.

In order to determine the most suitable steady-state and emergency electrical supply systems for the NUDETS program, a number of different power generating concepts were investigated. Several of the more important power equipment suppliers and manufacturers were consulted to obtain their suggestions for designs of power supply systems capable of satisfying the established criteria. On the whole, their response was quite encouraging and their assistance was found to be very helpful in the formulation of certain sections of this report. Visits were also made to existing installations in order to obtain first hand authoritative information concerning the reliability of the power supply systems and to observe the performance of the equipment under actual operating conditions.

As a result of these studies, it became apparent that the following uninterrupted power supply systems could be capable of satisfying the NUDETS requirements.

| TYPE | BASIC POWER SUPPLY | EMERGENCY POWER SOURCE |
|---|---|---|
| 'A-1' & 'A-2' | Motor-Generator (AC to AC) | Diesel Engine |
| 'B' | Motor-Generator (DC to AC) | Storage Batteries |
| 'C-1' & 'C-2' | Static Power Supply System (DC to AC) | Storage Batteries |
| 'D' | Motor-Generator (Type 'B') | Storage batteries with one-hour capacity, plus a diesel engine for extended emergency operation. |
| 'E-1' & 'E-2' | Static Power Supply System (Type 'C') | Storage batteries with one-hour capacity, plus a diesel engine for extended emergency operation. |

These five systems are described in detail in the following chapter.

# CHAPTER 3

## SYSTEMS DESCRIPTIONS

### A. Uninterrupted Diesel-Electric Power Generating Systems (Types 'A-1' and 'A-2')

The Uninterrupted Diesel-Electric Power Generating Systems consist essentially of the following basic components:

1) An alternating current motor to drive the A.C. generator.
2) An alternating current generator to supply the power to the critical load.
3) A heavy flywheel and magnetic clutch assembly.
4) A standard 1800 R.P.M. diesel engine.
5) Control instruments and switchgear equipment.

The units are delivered as complete, packaged systems, with all components mounted on a single, heavy, shock-isolated base ready for immediate installation.

During normal operation (Fig. 1-A), the motor is fed by the commercial power supply and drives the flywheel and generator which supplies the required load. The magnetic clutch is in the open (or de-energized) position, and the diesel engine's oil and water supply systems are circulated and maintained at operating temperatures by means of electric heaters.

Upon the failure of the commercial power source or its inability to meet predetermined standards, sensing relays open the commercial line contactor and energize the magnetic clutch. The inertia of

the flywheel carries the generator load and cranks the diesel engine up to operating speed, after which the engine assumes the full load (Fig. 1-B). Upon restoration of commercial power to a reliable quality, the diesel engine automatically synchronizes with it, the line contactor closes, the clutch disengages, and the engine shuts down, thus reverting to its standby condition.

A power supply system utilizing these units is isolated from the fluctuations or outages of the commercial power system because the load is always delivered by the unit's own generator and can therefore be relied upon to provide a supply of very high quality uninterrupted power at all times and under all conditions.

This type of power supply has been installed and operated in various types of military and industrial installations in this country and throughout the world. They have established a record of highly satisfactory performance while requiring a minimum of maintenance. The units come as a completely packaged system and include the switchgear and commercial line contactor. It is the switchgear and associated automatic controls which account for the largest proportional share of the cost of the unit.

B. Motor-Generator Set with Storage Batteries for Emergency Operation (Type 'B')

The "Two-Element" Uninterrupted Power Supply System consists basically of the following principal components.

1) A regulated D.C. static power supply which rectifies the incoming A.C. power supply into a D.C. power source.

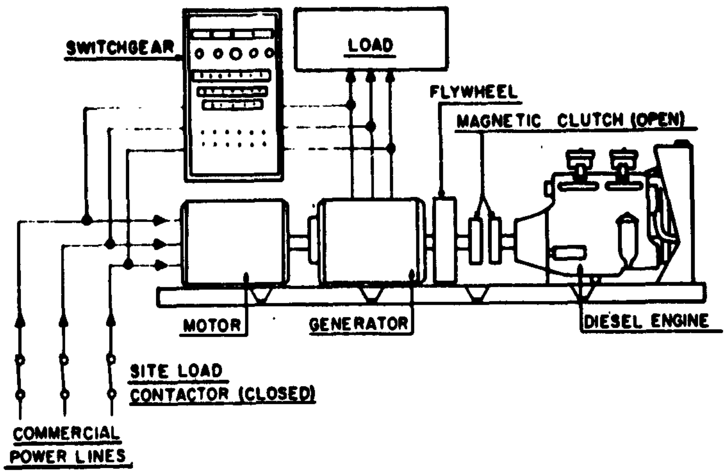



FIG. 1A

UNINTERRUPTED POWER SUPPLY SYSTEMS

TYPES "A-1" AND "A-2" - SCHEMATIC

NORMAL OPERATING CONDITION

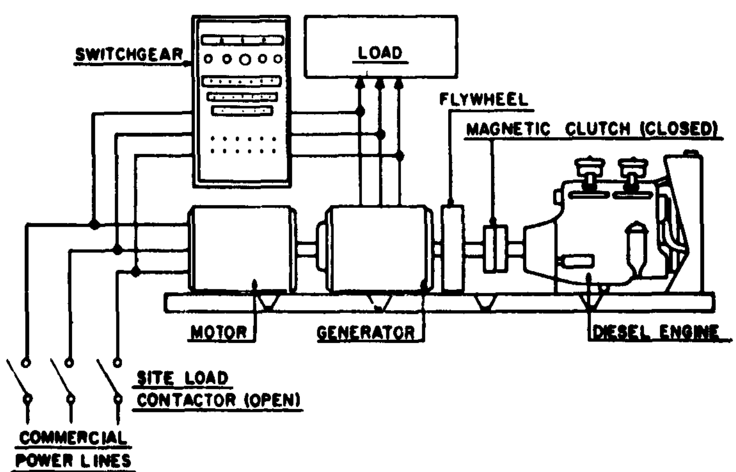



FIG. 1B

UNINTERRUPTED POWER SUPPLY SYSTEMS

TYPES "A-1" AND "A-2"- SCHEMATIC

EMERGENCY OPERATING CONDITION

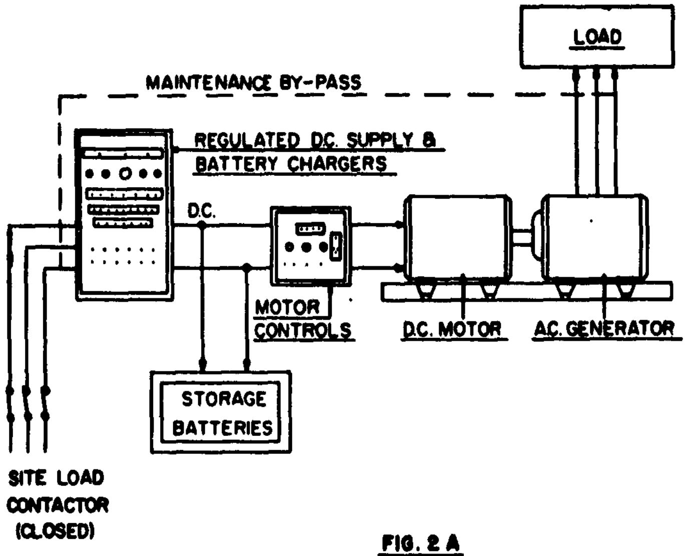



FIG. 2 A

UNINTERRUPTED POWER SUPPLY SYSTEMS

TYPE "B" - SCHEMATIC

NORMAL OPERATING CONDITION

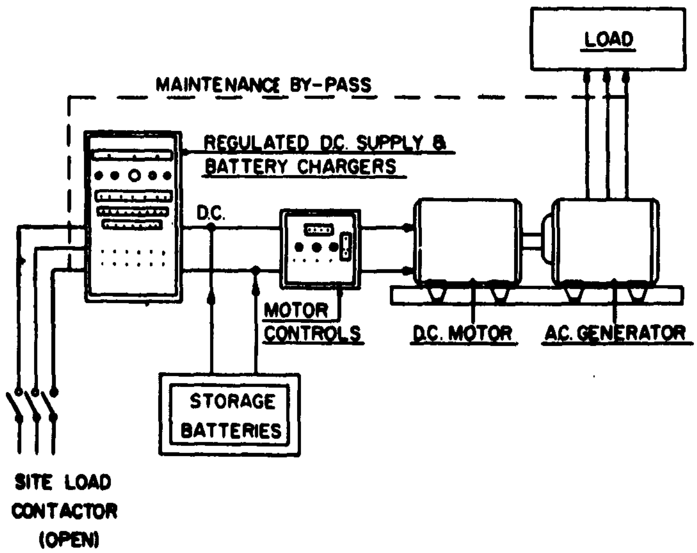



FIG. 2 B

UNINTERRUPTED POWER SUPPLY SYSTEMS

TYPE "B"- SCHEMATIC

EMERGENCY OPERATING CONDITION

2) Battery chargers capable of recharging the batteries from a discharged to a fully-charged condition within the time required and maintaining the fully-charged battery in a charged state during periods of normal use.

3) The emergency power source consisting of electrical storage batteries with sufficient capacity to supply the power requirements during the period of back-up operation.

4) A motor-generator set consisting of a Direct-Current motor driving an Alternating-Current generator.

All the items described above are fully proven, highly reliable machines and components of electrical generating systems, which, except for the storage batteries, have been assembled into one compact cabinet ready for rapid installation in any facility.

The critical load is supplied at all times and under all conditions by the A.C. generator which in turn is driven by the D.C. motor. During normal operation, power is supplied to the D.C. motor from the regulated D.C. static power supply which also provides the current to charge the batteries (Fig. 2-A). During periods of emergency operation (failure of the commercial power supply), the D.C. motor will draw its power from the storage batteries (Fig. 2-B).

This power system will provide maximum protection for the vital loads because these are never subjected to voltage or frequency transients and "spikes" associated with short circuit conditions in the incoming primary power source and which would occur if the system were connected directly to the incoming power supply.

Economic considerations present the most serious challenge to utilization of this type of power supply system in this program. The costs associated with the storage batteries and battery chargers exclude their applicability for extended periods of back-up operation. To overcome this severe limitation, a modified "Two Element" power supply system introducing a standard diesel-electric generator unit to supplement the batteries in the event of prolonged emergency operation has been examined in the Type 'D' System.

C. The Static Power Supply System (Types 'C-1' and 'C-2')

The Static Power Supply System has certain features which make it attractive for use as an uninterrupted power source. Such a system consists essentially of the following principal components:

1) A rectifier to change the incoming A.C. power to D.C. power.

2) Battery chargers sized to recharge the batteries within the time period desired and to maintain their charge during periods of normal operation.

3) The emergency power source consisting of storage batteries with a capacity sufficient to provide the power requirement during periods of emergency operation.

4) The static inverter which converts the D.C. power into Alternating Current.

During periods of normal operation (Fig. 3-A), the incoming alternating commercial power is converted by the rectifier into Direct Current to supply power to the static inverter and to maintain the

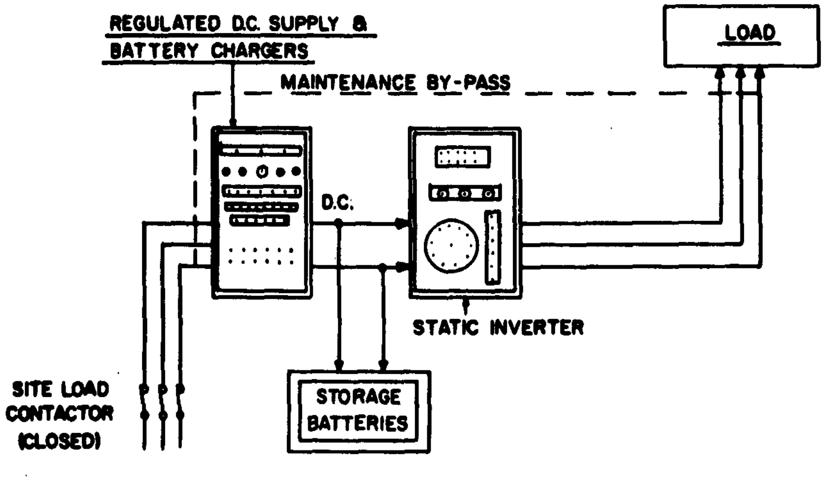



FIG. 3A

UNINTERRUPTED POWER SUPPLY SYSTEM

TYPE "C-1" AND "C-2" - SCHEMATIC

NORMAL OPERATING CONDITION

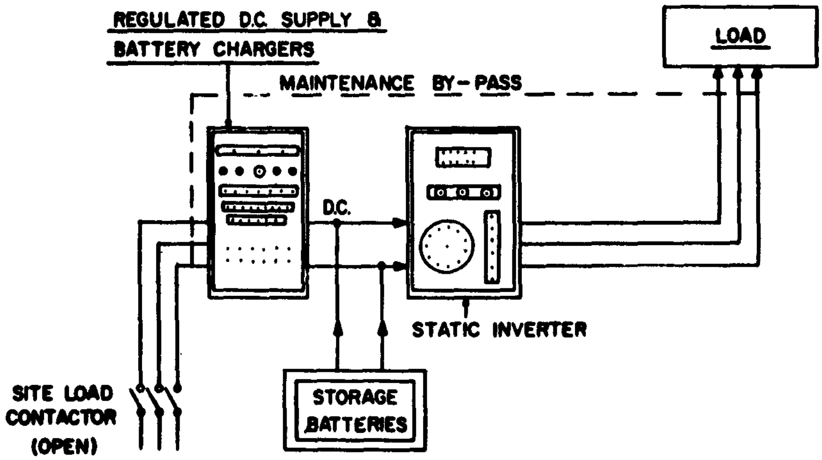



FIG. 3B

UNINTERRUPTED POWER SUPPLY SYSTEM

TYPE "C-1" AND "C-2" - SCHEMATIC

EMERGENCY OPERATING CONDITION

storage batteries at their proper charge level. Upon loss of the outside power source, the batteries immediately supply D.C. current to the inverter and the A.C. output to the critical load remains continuous (Fig. 3-B).

The most critical component of the static power supply system is the static inverter, which utilizes Silicon-Controlled Rectifiers (SCR) to switch Direct Current into a transformer in order to produce a sine-wave A.C. output. The power switching circuit accepts the D.C. energy and pulses it into the output transformer under control of the logic system.

The inverter, being solid state throughout, has no moving parts and consequently needs no lubrication. It therefore possesses a theoretically higher reliability than rotating machinery. The Silicon Controlled Rectifier is hermetically sealed against atmospheric reaction and does not wear out. They can therefore be run continuously at high efficiency, which is important in the specialized applications being analyzed in this report. Paradoxically. however, the principal loss of reliability lies in the fact that the static inverter is subject to line voltage transients if operated continuously. Nevertheless, it is felt that this problem can be overcome by utilization of transient suppressors and proper derating of components along with the smoothing-out effect provided by the batteries.

The total cost of static power supply systems varies directly with the length of emergency operation required. As the time increases, the major portion of the cost, namely batteries and battery chargers, rapidly becomes prohibitive. The basic power unit is also more expensive

than equivalent sized rotating machinery, although it can be presumed that their cost will be gradually reduced as their sales volume increases. An attempt to lower costs for extended operation has been made in the Type '<u>E</u>' systems by adding a standard diesel-electric generating set to the static power supply system. While this will decrease the total cost for longer periods of back-up operation, it is still more expensive than the normal power schemes presently available.

The static power supply system is a relatively new type of power generating method, and little information in the form of long-term reliability and operating data is available at the present time. Only a relatively small number of units (when compared to standard rotating equipment) have been installed in industrial facilities, but their application is rapidly increasing. It is felt that within the next twelve to eighteen months, sufficient data will become available to permit a more valid evaluation to be made as to the actual reliability of the static rectifiers to perform in accordance with specifications and to deliver the quality of power required by the system.

Therefore, in view of the cheaper costs and greater proven reliability of standard rotating equipment, it is felt that the static system should not be employed at the present time in manned power generating stations but that their eventual use be considered a few years hence if their costs are lowered and their reliability and ease of maintenance more fully proven.

## D. Motor-Generator Set with Storage Batteries and a Diesel Electric Power Unit (Type 'D')

This type of uninterrupted power supply system has been developed to combine the basic advantages of a motor-generator set (Type 'B') with the inherent economies found in operating a standard diesel engine during an extended time period.

This system is made up of the following major units:

1) A regulated D.C. static power supply which rectifies the incoming A.C. power supply into a D.C. power source.

2) Battery chargers capable of recharging the batteries from a discharged to a fully-charged condition within the time required, and of maintaining the fully-charged battery in a charged state during periods of normal use.

3) An emergency power source consisting of electrical storage batteries with sufficient capacity to supply the full power requirements during a period of one hour.

4) A motor-generator set consisting of a Direct-Current motor driving an Alternating-Current generator.

5) A standard diesel-electric engine-generator set for extended emergency operation.

All the above components are thoroughly proven, highly reliable pieces of machinery and equipment and can be easily and quickly installed in any facility.

During normal operation, the D.C. motor receives its power from the regulated D.C. static power supply which also charges the batteries (Fig. 4-A). The critical load is always supplied by the A.C. generator

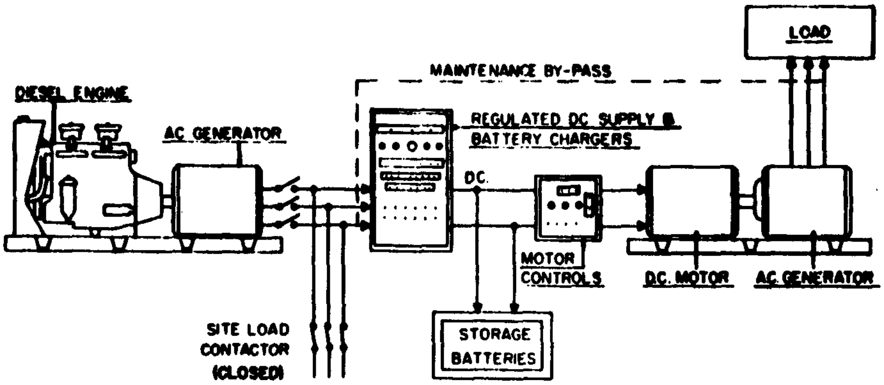



FIG. 4 A

UNINTERRUPTED POWER SUPPLY SYSTEM

TYPF "D"- SCHEMATIC

NORMAL OPERATING CONDITION

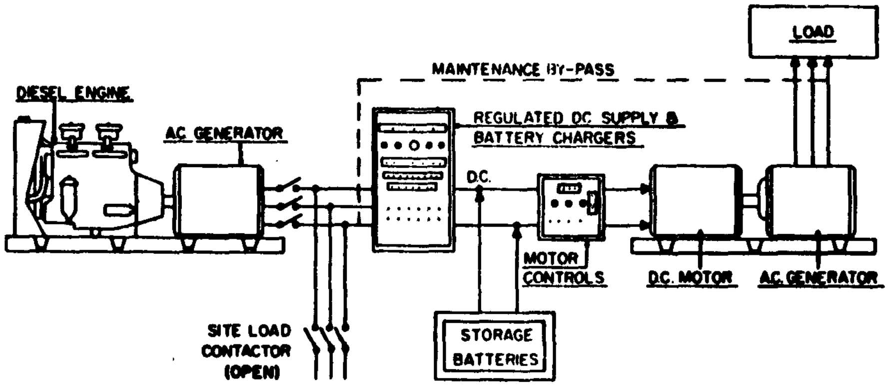



FIG. 4 B

UNINTERRUPTED POWER SUPPLY SYSTEM

TYPE "D"- SCHEMATIC

LIMITED EMERGENCY OPERATION

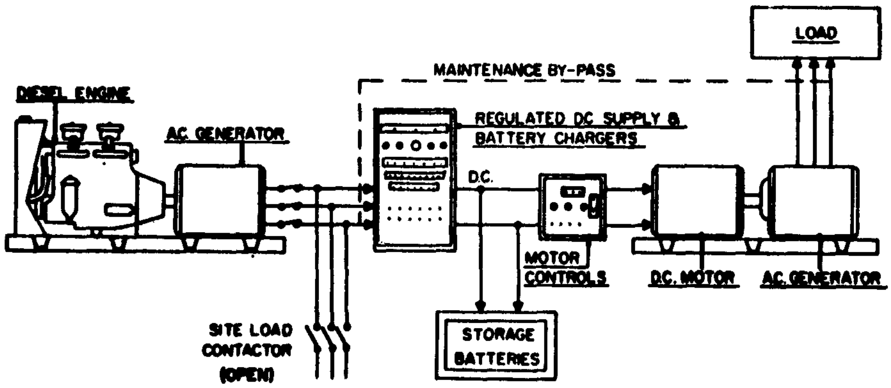



FIG. 4 C

UNINTERRUPTED POWER SUPPLY SYSTEM

TYPE "D"- SCHEMATIC

EXTENDED EMERGENCY OPERATION

C-9709

which is driven by the D.C. motor. Thus, the vital load is isolated at all times from unacceptable fluctuations and outages in the incoming commercial power supply.

When an emergency occurs, the batteries instantaneously start to supply the power to the D.C. motor (Fig. 4-B), and the diesel engine is started up either manually or automatically. Upon proper synchronization, the diesel's generator is brought on line, and power is once again fed into the system through the regulated D.C. power supply (Fig. 4-C). Upon restoration of commercial power to reliable and acceptable quality, the diesel unit automatically synchronizes with it and then shuts down, thus reverting to its standby condition.

As can be seen from the cost analysis in Chapter 4, this system, while much less expensive for emergency operations of long duration than the comparable battery "back-up" scheme shown in Type '<u>B</u>', is nevertheless more expensive than the uninterrupted motor-generator set of the Type '<u>A</u>' system. Furthermore, the problems of logistics and maintenance will also be proportionately increased due to the use of an additional piece of electrical generating equipment.

### <u>E</u>. <u>The Static Power Supply System with Storage Batteries and a Diesel Electric Power Unit</u> (<u>Types</u> '<u>E-1</u>' <u>&</u> '<u>E-2</u>')

This uninterrupted power supply system has been developed in a manner similar to Type '<u>D</u>', principally to reduce the prohibitive costs associated with using storage batteries as a power source during extended periods of emergency operation of the static power supply system.

This system consists of the following principal components:

1) A rectifier to change the incoming A.C. power to D.C. power.

2) Battery chargers sized to recharge the batteries within the time period desired and to maintain their charge during periods of normal operation.

3) An emergency power source consisting of electrical storage batteries with sufficient capacity to supply the power requirements for a period of one hour.

4) The static inverter which converts the D.C. power into alternating current.

5) A standard diesel-electric engine generator set for extended emergency operation.

During normal operations (Fig. 5-A), this power supply system functions in exactly the same manner as the Static Power Supply System described in Type 'C'. However, upon loss of the commercial power or during any other emergency period, the batteries will immediately begin to supply power to the static inverter which will deliver high quality power to the critical load (Fig. 5-B). The diesel engine will then be started and, upon synchronization, will deliver A.C. power into the system through the rectifier (Fig. 5-C). When acceptable commercial service is restored, the diesel engine will automatically synchronize with it and then shut down, reverting to its standby status.

While adding a standard diesel-electric generator set to the uninterruptible power system will greatly decrease the cost of extended emergency operation when compared to a battery-powered back-up scheme,

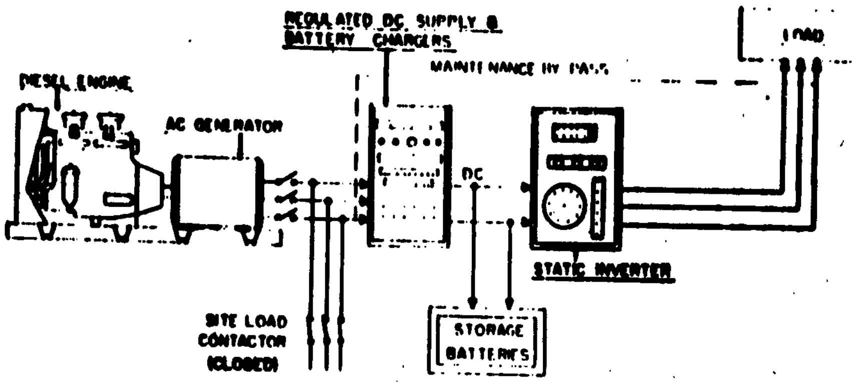



FIG 5A
UNINTERRUPTED POWER SUPPLY SYSTEM
TYPE "E-1" AND "E-2"- SCHEMATIC
NORMAL OPERATING CONDITION

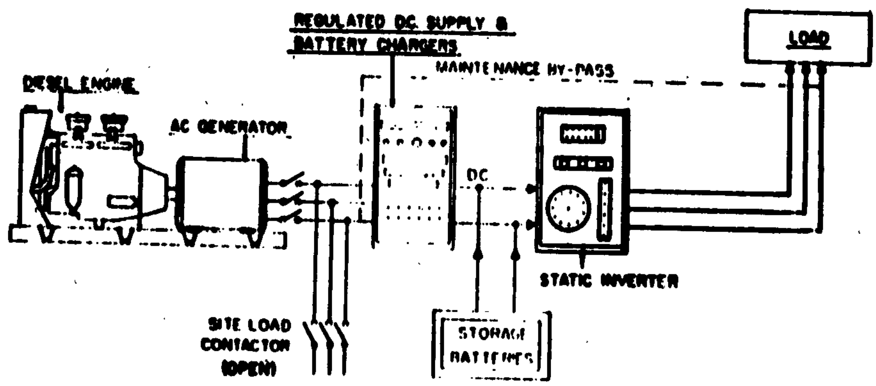



FIG 5B
UNINTERRUPTED POWER SUPPLY SYSTEM
TYPE "E-1" AND "E-2"- SCHEMATIC
LIMITED EMERGENCY OPERATION

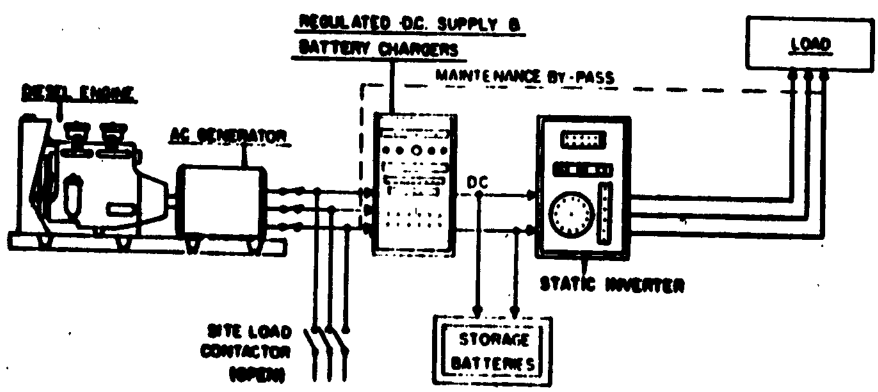



FIG. 5C
UNINTERRUPTED POWER SUPPLY SYSTEM
TYPE "E-1" AND "E-2"- SCHEMATIC
EXTENDED EMERGENCY OPERATION

the total cost of this combined system is still greater than that of the motor-generator unit shown in Types 'A-1' and 'A-2'.

It is also necessary to mention the increased maintenance and logistic costs which will be associated with this combined system when compared to Types 'A-1' and 'A-2'.

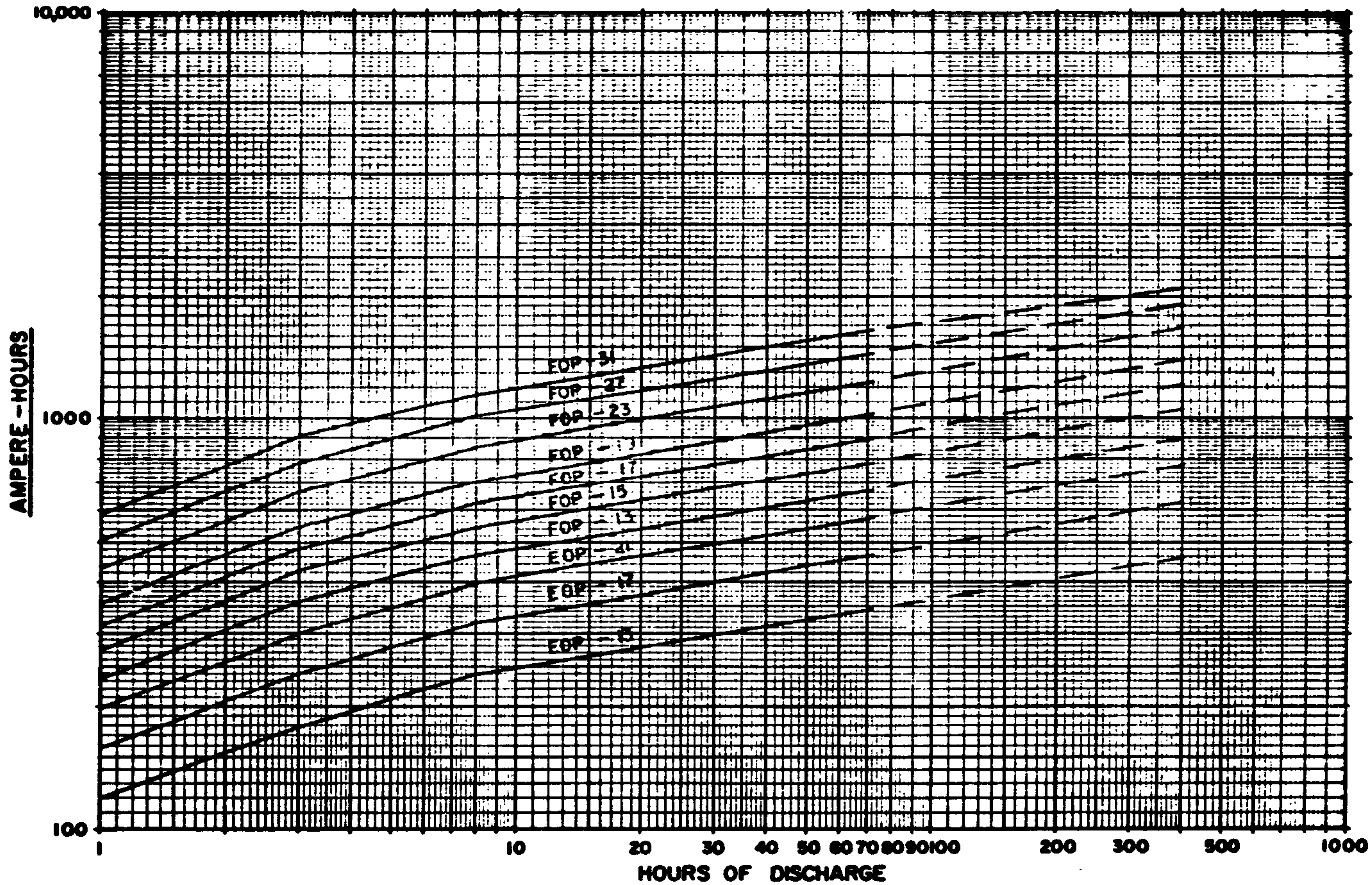
# CHAPTER 4

## COST ANALYSIS

The itemized estimating data used in arriving at the final total costs for the various power supply systems are listed in the following pages.

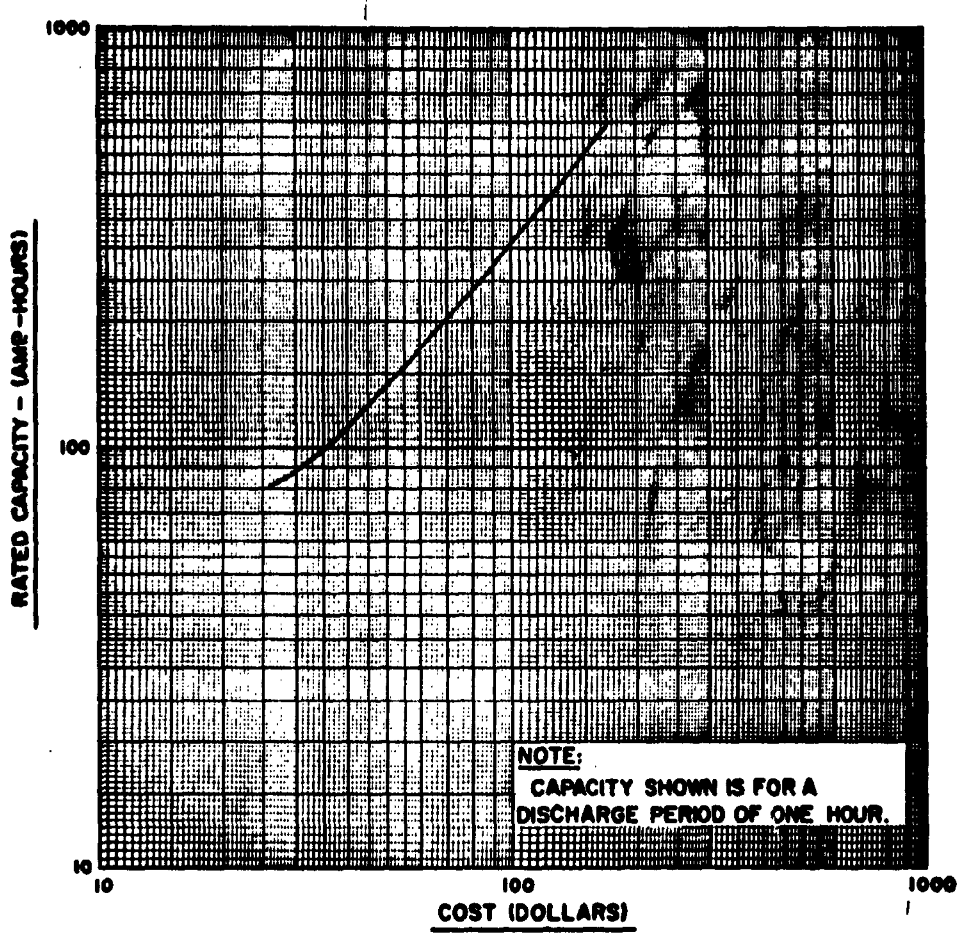
Since certain of the cost items were supplied by various equipment manufacturers and suppliers as proposals and engineering estimates, this information could be considered as being of a private nature. Therefore, a list of coded references identifying the various power supply systems with their respective manufacturers has been supplied to Department D-17 for their use. Further information and details can also be obtained from brochures and documents on file with the author.

The total system costs shown in the following pages are made up of the equipment costs for a single power unit plus an allowance of 15% for installation and 15% for contingencies. It is recognized that the latter two items may vary slightly depending upon the peculiarities associated with individual site locations, nature of the facility, etc. Furthermore, it should be pointed out that the equipment costs are based upon delivery prices at the manufacturer's plant and therefore do not include the contractor's profit and overhead. However, it is felt that these items will not invalidate the <u>relative</u> cost advantages of the various systems, since they would affect all systems proportionately.




**TYPICAL DISCHARGE CURVES LEAD-ACID TYPE BATTERIES**

FIG. 6




TYPICAL COSTS-LEAD ACID TYPE BATTERIES

FIG. 7

1A-9624

## COST ESTIMATE — TYPE "A-1" - 3 KW LOAD

## MOTOR — GENERATOR SET WITH DIESEL ENGINE

| DURATION OF EMERGENCY OPERATION | 1 PRIME EQUIPMENT COST | 2 EQUIPMENT ACCESSORIES COST | 3 TOTAL EQUIPMENT COST | 4 INSTALLATION COST (15% OF 3) | 5 CONTINGENCY COST (15% OF 3+4) | 6 TOTAL SYSTEM COST (3+4+5) |
|---|---|---|---|---|---|---|
| 1 HOUR | $3,600 | $2,900 | $6,500 | $975 | $1,120 | $8,595 |
| 3 HOURS | | | | | | |
| 8 HOURS | | | | | | |
| 12 HOURS | | | | | | |
| 36 HOURS | | | | | | |
| 72 HOURS | | | | | | |
| 168 HOURS | $3,600 | $3,500 | $7,100 | $1070 | $1,230 | $9,400 |

FIG. 8

## COST ESTIMATE — TYPE "A-2" - 3 KW LOAD

### MOTOR – GENERATOR SET WITH DIESEL ENGINE

| DURATION OF EMERGENCY OPERATION | 1 PRIME EQUIPMENT COST | 2 EQUIPMENT ACCESSORIES COST | 3 TOTAL EQUIPMENT COST | 4 INSTALLATION COST (15% OF 3) | 5 CONTINGENCY COST (15% OF 3+4) | 6 TOTAL SYSTEM COST (3+4+5) |
|---|---|---|---|---|---|---|
| 1 HOUR | $11,500 | $2,900 | $14,400 | $2,160 | $2,500 | $19,060 |
| 3 HOURS | | | | | | |
| 8 HOURS | | | | | | |
| 12 HOURS | | | | | | |
| 36 HOURS | | | | | | |
| 72 HOURS | | | | | | |
| 168 HOURS | $11,500 | $3,500 | $15,000 | $2,250 | $2,590 | $19,840 |

FIG. 9

IA-10,425

# COST ESTIMATE — TYPE "B" - 3 KW LOAD

## MOTOR GENERATOR UNIT WITH STORAGE BATTERIES

| DURATION OF EMERGENCY OPERATION | 1 PRIME EQUIPMENT COST | 2 BATTERIES AND RACKS COST | 3 BATTERY CHARGERS COST | 4 TOTAL EQUIPMENT COST (1 + 2 + 3) | 5 INSTALLATION COST (15% OF 4) | 6 CONTINGENCY COST (15% OF 4+5) | 7 TOTAL SYSTEM COST (4 + 5 + 6) |
|---|---|---|---|---|---|---|---|
| 1 HOUR | $13,064 | $1,725 | —— * | $14,789 | $2,220 | $2,500 | $19,509 |
| 3 HOURS | $13,064 | $3,175 | —— * | $16,239 | $2,440 | $2,800 | $21,479 |
| 8 HOURS | $13,064 | $5,610 | —— * | $18,674 | $2,800 | $3,220 | $24,694 |
| 12 HOURS | $13,064 | $6,850 | $3,827 | $23,741 | $3,500 | $4,100 | $[illegible]1,491 |
| 36 HOURS | $13,064 | $15,000 | $6,380 | $34,444 | $5,180 | $5,950 | $45,574 |
| 72 HOURS | $13,064 | $24,920 | $8,530 | $46,514 | $7,000 | $8,050 | $61,564 |
| 168 HOURS | $13,064 | $40,100 | $9,400 | $71,584 | $10,750 | $12,350 | $94,684 |

* BATTERY CHARGERS FORM AN INTEGRAL PART OF THE PRIME POWER UNIT.

FIG. 10

IA-10,426

# COST ESTIMATE — TYPE "C-1" — 3 KW LOAD

## STATIC POWER SUPPLY SYSTEM WITH STORAGE BATTERIES

| DURATION OF EMERGENCY OPERATION | 1<br>PRIME EQUIPMENT COST | 2<br>BATTERIES AND RACKS COST | 3<br>BATTERY CHARGERS COST | 4<br>TOTAL EQUIPMENT COST (1 + 2 + 3) | 5<br>INSTALLATION COST (15% OF 4) | 6<br>CONTINGENCY COST (15% OF 4 + 5) | 7<br>TOTAL SYSTEM COST (4 + 5 + 6) |
|---|---|---|---|---|---|---|---|
| 1 HOUR | $10,306 | $688 | $1,881 | $12,875 | $1,930 | $2,200 | $17,025 |
| 3 HOURS | $10,306 | $1,755 | $1,881 | $13,942 | $2,090 | $2,410 | $18,442 |
| 8 HOURS | $10,306 | $3,285 | $2,836 | $16,507 | $2,480 | $2,850 | $21,757 |
| 12 HOURS | $10,306 | $4,198 | $3,557 | $18,141 | $2,730 | $3,140 | $24,011 |
| 36 HOURS | $10,306 | $11,116 | $7,114 | $28,616 | $4,300 | $4,950 | $37,866 |
| 72 HOURS | $10,306 | $18,525 | $14,228 | $43,139 | $6,450 | $7,420 | $57,009 |
| 168 HOURS | $10,306 | $37,950 | $19,852 | $68,108 | $10,200 | $11,700 | $90,008 |

FIG. 11

IA-10,427

# COST ESTIMATE – TYPE "C-2" – 3KW LOAD

## STATIC POWER SUPPLY SYSTEM WITH STORAGE BATTERIES

| DURATION OF EMERGENCY OPERATION | 1 PRIME EQUIPMENT COST | 2 BATTERIES AND RACKS COST | 3 BATTERY CHARGERS COST | 4 TOTAL EQUIPMENT COST (1 + 2 + 3) | 5 INSTALLATION COST (15% OF 4) | 6 CONTINGENCY COST (15% OF 4 + 5) | 7 TOTAL SYSTEM COST (4 + 5 + 6) |
|---|---|---|---|---|---|---|---|
| 1 HOUR | $12,000 | $1725 | ——* | $13,725 | $2,070 | $2,370 | $18,165 |
| 3 HOURS | $12,000 | $2,260 | ——* | $14,260 | $2,140 | $2,400 | $18,800 |
| 8 HOURS | $12,000 | $4,390 | ——* | $16,390 | $2,460 | $2,820 | $21,670 |
| 12 HOURS | $12,000 | $5,610 | $3,827 | $21,437 | $3,220 | $3,700 | $28,357 |
| 36 HOURS | $12,000 | $13,700 | $5,300 | $31,000 | $4,700 | $5,490 | $42,950 |
| 72 HOURS | $12,000 | $24,750 | $6,220 | $42,970 | $6,440 | $7,400 | $56,800 |
| 168 HOURS | $12,000 | $42,000 | $10,700 | $64,700 | $9,700 | $11,200 | $85,600 |

* BATTERY CHARGERS FORM AN INTEGRAL PART OF THE PRIME POWER UNIT.

FIG. 12

IA-10,428

# COST ESTIMATE — TYPE "D" - 3 KW LOAD

## MOTOR - GENERATOR UNIT (TYPE "B") WITH STORAGE BATTERIES AND DIESEL ENGINE

| DURATION OF EMERGENCY OPERATION | 1 PRIME EQUIPMENT COST | 2 BATTERIES AND RACKS COST | 3 TOTAL EQUIPMENT COST (1 + 2) | 4 INSTALLATION COST (15 % OF 3) | 5 CONTINGENCY COST (15% OF 3 + 4) | 6 TOTAL SYSTEM COST (3 + 4 + 5) |
|---|---|---|---|---|---|---|
| 1 HOUR | $ 14,564 * | $ 1,725 | $16,289 | $ 2,440 | $2,810 | $21,539 |
| 3 HOURS | | | | | | |
| 8 HOURS | | | | | | |
| 12 HOURS | | | | | | |
| 36 HOURS | | | | | | |
| 72 HOURS | | | | | | |
| 168 HOURS | $ 15,164 * | $ 1,725 | $ 16,889 | $2,530 | $2,920 | $22,339 |

* COST INCLUDES INTEGRAL BATTERY CHARGER, DIESEL ELECTRIC GENERATOR AND ACCESSORIES.

FIG. 13

## COST ESTIMATE — TYPE "E-1" — 3 KW LOAD

### STATIC POWER SUPPLY SYSTEM (TYPE "C-1") WITH STORAGE BATTERIES AND DIESEL ENGINE

| DURATION OF EMERGENCY OPERATION | 1 PRIME EQUIPMENT COST | 2 BATTERIES AND RACKS COST | 3 BATTERY CHARGERS COST | 4 TOTAL EQUIPMENT COST (1 + 2 + 3) | 5 INSTALLATION COST (15% OF 4) | 6 CONTINGENCY COST (15% OF 4 + 5) | 7 TOTAL SYSTEM COST (4 + 5 + 6) |
|---|---|---|---|---|---|---|---|
| 1 HOUR | $ 11,386 * | $ 688 | $ 1,801 | $13,875 | $ 2,080 | $ 2,390 | $18,345 |
| 3 HOURS | | | | | | | |
| 8 HOURS | | | | | | | |
| 12 HOURS | | | | | | | |
| 36 HOURS | | | | | | | |
| 72 HOURS | | | | | | | |
| 168 HOURS | $ 11,986 * | $ 688 | $ 1,801 | $14,475 | $ 2,160 | $ 2,500 | $19,135 |

* COST INCLUDES THE DIESEL ELECTRIC GENERATOR AND ACCESSORIES.

FIG. 14

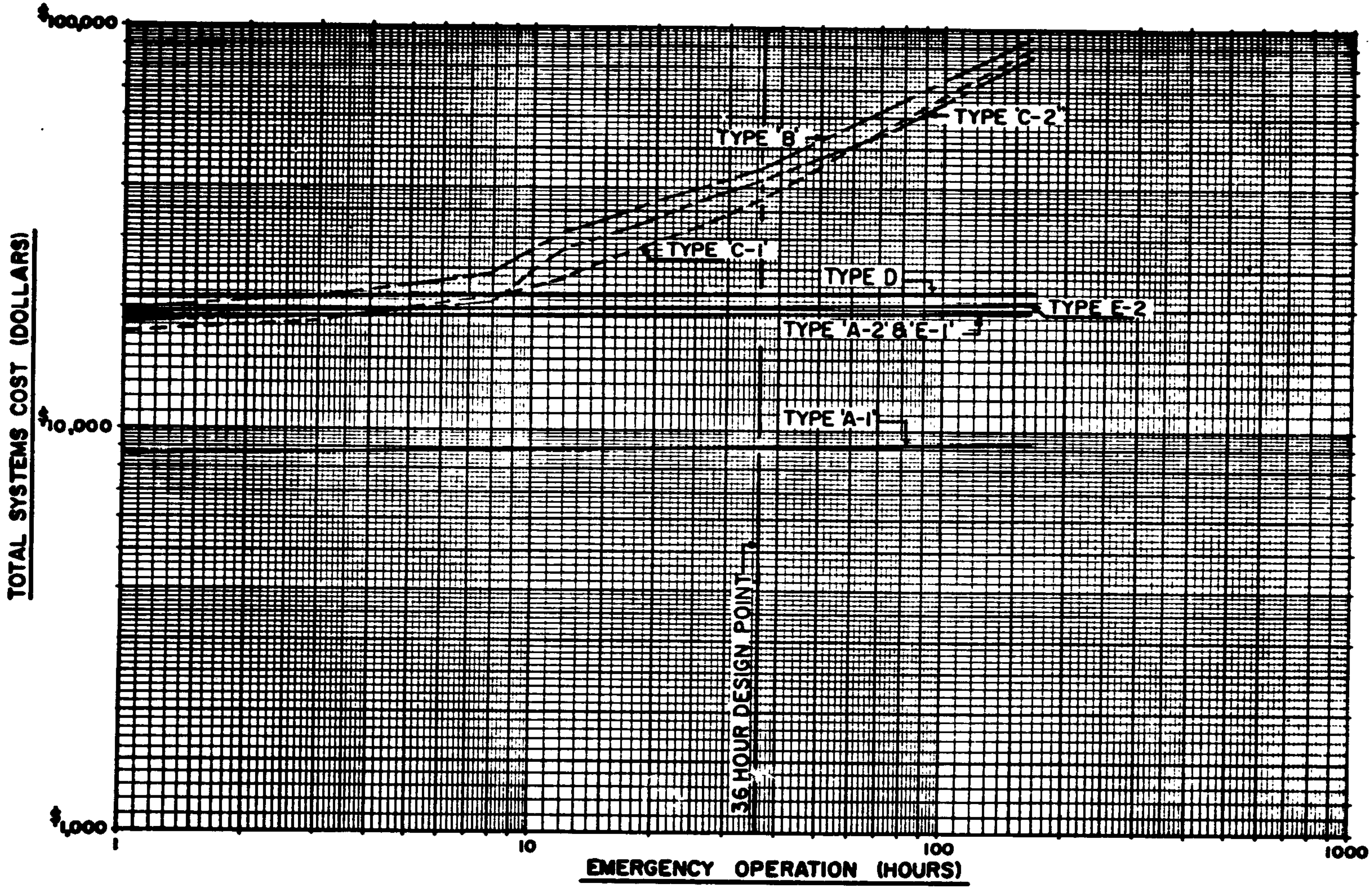
## COST ESTIMATE — TYPE "E-2" - 3 KW LOAD

### STATIC POWER SUPPLY SYSTEM (TYPE "C-2") WITH STORAGE BATTERIES AND DIESEL ENGINE

| DURATION OF EMERGENCY OPERATION | 1 PRIME EQUIPMENT COST | 2 BATTERIES AND RACKS COST | 3 TOTAL EQUIPMENT COST (1 + 2) | 4 INSTALLATION COST (15 % OF 3) | 5 CONTINGENCY COST (15% OF 3 + 4) | 6 TOTAL SYSTEM COST (3 + 4 + 5) |
|---|---|---|---|---|---|---|
| 1 HOUR | $ 13,000 * | $ 1,725 | $14,725 | $ 2,210 | $ 2,540 | $ 19,475 |
| 3 HOURS | | | | | | |
| 8 HOURS | | | | | | |
| 12 HOURS | | | | | | |
| 36 HOURS | | | | | | |
| 72 HOURS | | | | | | |
| 168 HOURS | $ 13,600 * | $ 1,725 | $ 15,325 | $ 2,290 | $ 2,640 | $ 20,255 |

* COST INCLUDES INTEGRAL BATTERY CHARGER, DIESEL ELECTRIC GENERATOR AND ACCESSORIES.

FIG. 15




## 3 KW EMERGENCY POWER SYSTEMS

## COST COMPARISON

FIG. 16

IA-10,432

## COST ESTIMATE — TYPE "A-1" — 50 KW LOAD

### MOTOR — GENERATOR SET WITH DIESEL ENGINE

| DURATION OF EMERGENCY OPERATION | 1 PRIME EQUIPMENT COST | 2 EQUIPMENT ACCESSORIES COST | 3 TOTAL EQUIPMENT COST | 4 INSTALLATION COST (15% OF 3) | 5 CONTINGENCY COST (15% OF 3+4) | 6 TOTAL SYSTEM COST (3+4+5) |
|---|---|---|---|---|---|---|
| 1 HOUR | $ 27,500 | $ 4,250 | $31,750 | $ 4,700 | $5000 | $42,000 |
| 3 HOURS | | | | | | |
| 8 HOURS | | | | | | |
| 12 HOURS | | | | | | |
| 36 HOURS | | | | | | |
| 72 HOURS | | | | | | |
| 168 HOURS | $ 27,500 | $ 4,850 | $ 32,350 | $ 4,850 | $ 5,500 | $ 42,700 |

FIG. 17

1A-10,458

## COST ESTIMATE — TYPE "A-2"- 50KW LOAD

### MOTOR - GENERATOR SET WITH DIESEL ENGINE

| DURATION OF EMERGENCY OPERATION | 1 PRIME EQUIPMENT COST | 2 EQUIPMENT ACCESSORIES COST | 3 TOTAL EQUIPMENT COST | 4 INSTALLATION COST (15 % OF 3) | 5 CONTINGENCY COST (15% OF 3+4) | 6 TOTAL SYSTEM COST (3+4+5) |
|---|---|---|---|---|---|---|
| 1 HOUR | $ 28,500 | $ 4,250 | $ 32,750 | $ 4,900 | $ 5,650 | $ 43,300 |
| 3 HOURS | | | | | | |
| 8 HOURS | | | | | | |
| 12 HOURS | | | | | | |
| 36 HOURS | | | | | | |
| 72 HOURS | | | | | | |
| 168 HOURS | $ 28,500 | $ 4,850 | $ 33,350 | $ 5,000 | $ 5,750 | $ 44,100 |

FIG. 18

IA-10,434

# COST ESTIMATE — TYPE "B" — 50KW LOAD

## MOTOR-GENERATOR UNIT WITH STORAGE BATTERIES

| DURATION OF EMERGENCY OPERATION | 1 PRIME EQUIPMENT COST | 2 BATTERIES AND RACKS COST | 3 BATTERY CHARGERS COST | 4 TOTAL EQUIPMENT COST (1 + 2 + 3) | 5 INSTALLATION COST (15% OF 4) | 6 CONTINGENCY COST (15% OF 4 + 5) | 7 TOTAL SYSTEM COST (4 + 5 + 6) |
|---|---|---|---|---|---|---|---|
| 1 HOUR | $35,000 | $16,400 | —* | $51,400 | $7,720 | $8,900 | $68,020 |
| 3 HOURS | $35,000 | $32,800 | $8,530 | $78,330 | $11,500 | $13,200 | $101,050 |
| 8 HOURS | $35,000 | $65,000 | $17,000 | $117,000 | $17,600 | $20,300 | $155,500 |
| 12 HOURS | $35,000 | $90,100 | $18,000 | $143,900 | $21,500 | $24,800 | $190,200 |
| 36 HOURS | $35,000 | $211,000 | $58,400 | $302,400 | $45,300 | $51,000 | $309,500 |
| 72 HOURS | $35,000 | $378,000 | $112,000 | $525,000 | $78,700 | $90,500 | $694,200 |
| 168 HOURS | $35,000 | $799,200 | $132,000 | $966,200 | $145,000 | $167,000 | $1,278,200 |

* BATTERY CHARGERS ARE AN INTEGRAL PART OF THE PRIME POWER UNIT.

FIG. 19

## COST ESTIMATE — TYPE "C-1" — 50KW LOAD

### STATIC POWER SUPPLY SYSTEM WITH STORAGE BATTERIES

| DURATION OF EMERGENCY OPERATION | 1 PRIME EQUIPMENT COST | 2 BATTERIES AND RACKS COST | 3 BATTERY CHARGERS COST | 4 TOTAL EQUIPMENT COST (1 + 2 + 3) | 5 INSTALLATION COST (15% OF 4) | 6 CONTINGENCY COST (15% OF 4 + 5) | 7 TOTAL SYSTEM COST (4 + 5 + 6) |
|---|---|---|---|---|---|---|---|
| 1 HOUR | $62,696 | $10,530 | $4,436 | $77,662 | $11,700 | $13,400 | $102,762 |
| 3 HOURS | $62,696 | $21,000 | $5,300 | $89,136 | $13,400 | $15,300 | $117,836 |
| 8 HOURS | $62,696 | $42,120 | $9,230 | $114,046 | $17,100 | $19,700 | $150,846 |
| 12 HOURS | $62,696 | $63,200 | $15,700 | $141,596 | $21,200 | $24,400 | $187,196 |
| 36 HOURS | $62,696 | $147,300 | $38,920 | $248,916 | $37,100 | $42,900 | $328,916 |
| 72 HOURS | $62,696 | $242,800 | $78,500 | $383,996 | $57,400 | $66,300 | $507,696 |
| 168 HOURS | $62,696 | $517,000 | $102,000 | $681,696 | $102,000 | $117,500 | $901,196 |

FIG. 20

IA-10,436

## COST ESTIMATE — TYPE "C-2" — 50KW LOAD

### STATIC POWER SUPPLY SYSTEM WITH STORAGE BATTERIES

| DURATION OF EMERGENCY OPERATION | 1 PRIME EQUIPMENT COST | 2 BATTERIES AND RACKS COST | 3 BATTERY CHARGERS COST | 4 TOTAL EQUIPMENT COST (1 + 2 + 3) | 5 INSTALLATION COST (15% OF 4) | 6 CONTINGENCY COST (15% OF 4 + 5) | 7 TOTAL SYSTEM COST (4 + 5 + 6) |
|---|---|---|---|---|---|---|---|
| 1 HOUR | $ 42,000 | $13,700 | $ 5,300 | $ 61,000 | $ 9,250 | $ 10,500 | $ 80,850 |
| 3 HOURS | $ 42,000 | $ 28,400 | $ 7,850 | $ 78,250 | $ 11,000 | $ 13,200 | $ 100,850 |
| 8 HOURS | $ 42,000 | $ 52,750 | $ 15,700 | $ 110,450 | $ 16,500 | $ 19,000 | $ 145,950 |
| 12 HOURS | $ 42,000 | $ 73,650 | $ 18,000 | $ 132,650 | $ 19,900 | $ 22,900 | $ 175,650 |
| 36 HOURS | $ 42,000 | $ 179,850 | $ 45,000 | $ 265,850 | $ 39,800 | $ 45,700 | $ 351,150 |
| 72 HOURS | $ 42,000 | $ 318,500 | $ 90,000 | $ 450,000 | $ 67,500 | $ 77,500 | $ 595,000 |
| 168 HOURS | $ 42,000 | $ 664,400 | $ 111,000 | $ 817,400 | $ 125,000 | $ 141,500 | $ 1,083,900 |

FIG. 21

## COST ESTIMATE — TYPE "D"-50 KW LOAD

**MOTOR-GENERATOR UNIT (TYPE "B") WITH STORAGE BATTERIES AND DIESEL ENGINE**

| DURATION OF EMERGENCY OPERATION | 1 PRIME EQUIPMENT COST | 2 BATTERIES AND RACKS COST | 3 TOTAL EQUIPMENT COST (1+2) | 4 INSTALLATION COST (15% OF 3) | 5 CONTINGENCY COST (15% OF 3+4) | 6 TOTAL SYSTEM COST (3+4+5) |
|---|---|---|---|---|---|---|
| 1 HOUR | $50,025 * | $16,400 | $67,025 | $10,100 | $11,600 | $88,725 |
| 3 HOURS | | | | | | |
| 8 HOURS | | | | | | |
| 12 HOURS | | | | | | |
| 36 HOURS | | | | | | |
| 72 HOURS | | | | | | |
| 168 HOURS | $51,225 * | $16,400 | $67,625 | $10,200 | $11,700 | $89,525 |

* COST INCLUDES INTEGRAL BATTERY CHARGER, DIESEL ELECTRIC GENERATOR AND ACCESSORIES.

FIG. 22

## COST ESTIMATE — TYPE "E-1" — 50KW LOAD

### STATIC POWER SUPPLY SYSTEM (TYPE "C-1") WITH STORAGE BATTERIES AND DIESEL ENGINE

| DURATION OF EMERGENCY OPERATION | 1 PRIME EQUIPMENT COST | 2 BATTERIES AND RACKS COST | 3 BATTERY CHARGERS COST | 4 TOTAL EQUIPMENT COST (1 + 2 + 3) | 5 INSTALLATION COST (15% OF 4) | 6 CONTINGENCY COST (15% OF 4 + 5) | 7 TOTAL SYSTEM COST (4 + 5 + 6) |
|---|---|---|---|---|---|---|---|
| 1 HOUR | $ 78,321 * | $10,530 | $ 4,436 | $ 93,287 | $14,000 | $16,100 | $ 123,387 |
| 3 HOURS | | | | | | | |
| 8 HOURS | | | | | | | |
| 12 HOURS | | | | | | | |
| 36 HOURS | | | | | | | |
| 72 HOURS | | | | | | | |
| 168 HOURS | $ 78,921 | $ 10,530 | $ 4,436 | $ 93,887 | $ 14,100 | $ 16,200 | $ 124,187 |

* COST INCLUDES THE DIESEL ELECTRIC GENERATOR AND ACCESSORIES.

FIG. 23

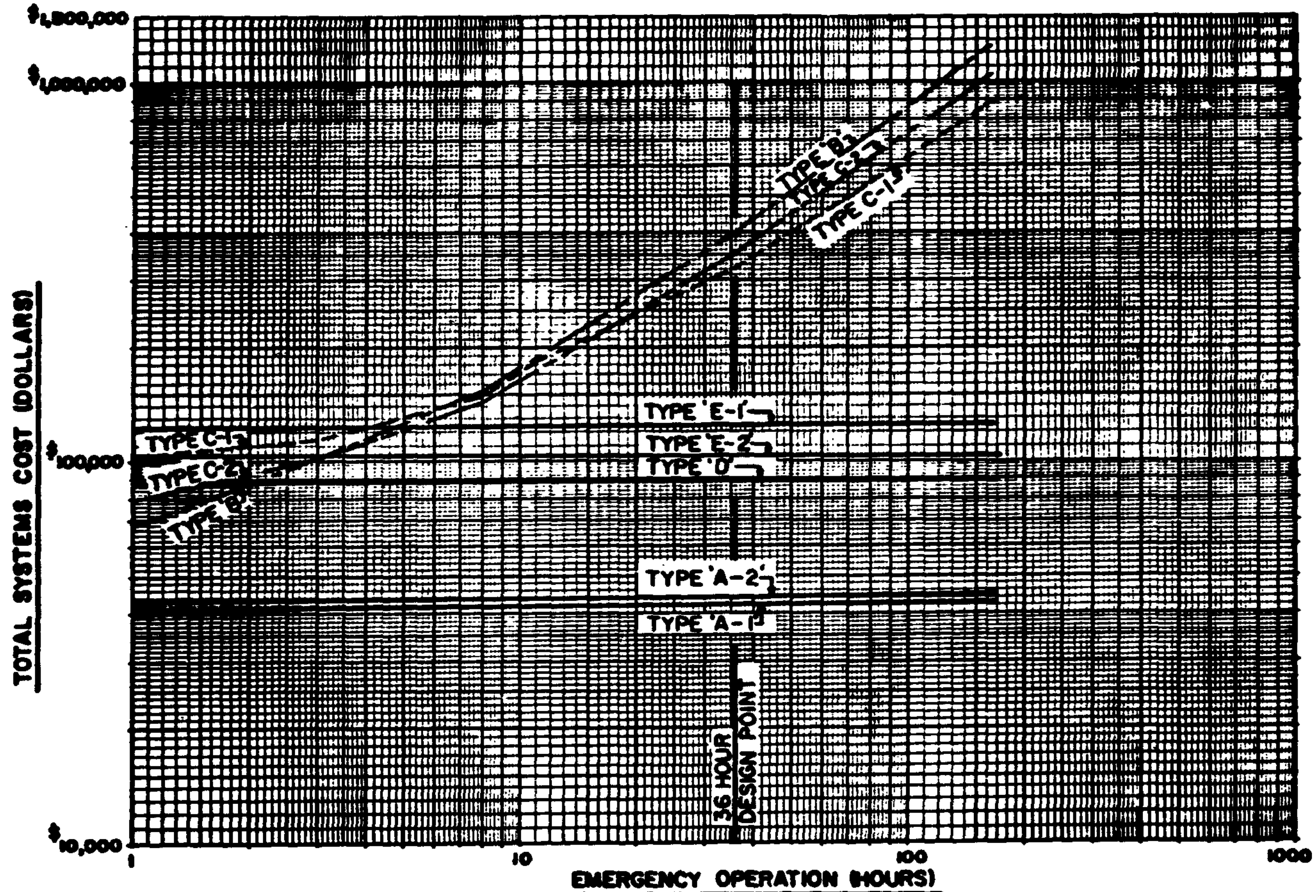
## COST ESTIMATE — TYPE "E-2" - 50KW LOAD

### STATIC POWER SUPPLY SYSTEM (TYPE "C-2") WITH STORAGE BATTERIES AND DIESEL ENGINE

| DURATION OF EMERGENCY OPERATION | 1 PRIME EQUIPMENT COST | 2 BATTERIES AND RACKS COST | 3 BATTERY CHARGERS COST | 4 TOTAL EQUIPMENT COST (1 + 2 + 3) | 5 INSTALLATION COST (15% OF 4) | 6 CONTINGENCY COST (15% OF 4 + 5) | 7 TOTAL SYSTEM COST (4 + 5 + 6) |
|---|---|---|---|---|---|---|---|
| 1 HOUR | $ 57,625 * | $ 14,700 | $ 5,300 | $ 76,705 | $ 11,500 | $ 13,250 | $ 101,455 |
| 3 HOURS | | | | | | | |
| 8 HOURS | | | | | | | |
| 12 HOURS | | | | | | | |
| 36 HOURS | | | | | | | |
| 72 HOURS | | | | | | | |
| 168 HOURS | $ 58,225 * | $ 13,700 | $ 5,300 | $ 77,305 | $ 11,600 | $ 13,350 | $ 102,255 |

* COST INCLUDES THE DIESEL ELECTRIC GENERATOR AND ACCESSORIES.

FIG. 24




## 50 KW EMERGENCY POWER SYSTEMS

## COST COMPARISON

FIG. 25

# CHAPTER 5

# CONCLUSIONS AND RECOMMENDATIONS

## 1. CONCLUSIONS

This ..port presents the results of an investigation into the various methods of providing highly reliable, uninterruptible electrical power supplies for the NUDETS program.

Of the five systems analyzed, Types 'A-1' and 'A-2', the motor-generator set connected by means of a magnetic clutch to a diesel engine for back-up during emergency operation, appears to be the most thoroughly developed and proven. This is due to the many years of actual operation under conditions similar to those which will exist at the manned stations of the NUDETS projects. As a result of constant improvements in the performance characteristics of these units, they have now acquired a very high degree of reliability, making them quite suitable for application in all stations of this program.

The Type 'B' system utilizing thoroughly proven components of electrical generating systems (rectifiers, motors, generators, etc.) is also capable of providing the high quality, uninterrupted power supply required by the NUDETS program, although at a rather serious cost premium.

For the unmanned stations with short emergency operational period, the use of a Type 'C' static Power Supply System could eventually be envisioned when more extensive reliability and operational data becomes available. Due to its rather recent development, such information is presently still very limited.

However, the principal disadvantage of Types 'B' and 'C' is the heavy expense associated with the large number of storage batteries and their accompanying battery chargers. For larger loads and emergencies of long duration, the cost of these systems becomes prohibitive.

A compromise solution to reduce these costs was examined in Types 'D' and 'E', wherein a storage battery system with a capacity for one hour's emergency operation would be provided. During this time, a conventional diesel-electric generator set would be started up and upon synchronization, would supply the critical load. However, the cost of these systems is still greater than the cost for Types 'A-1' and 'A-2', and further maintenance and logistics problems are introduced due to the utilization of a more complex power generating system.

## 2. RECOMMENDATION

Of the systems analyzed, it therefore appears that Types 'A-1' and 'A-2' offer the most economical solution for providing the type of high quality uninterruptible power supply required by both Type I and Type II installations respectively. This recommendation is based not only on the lowest costs involved for all periods of emergency operation but also on the demonstrated ability of these packaged power units to provide the highly reliable power supply demanded by the sophisticated electronic components making up the total NUDETS system.

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